Agronomic and environmental factors influence weed composition and canola competitiveness in southern Manitoba

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[1]*Department of Plant Science, University of Manitoba, Winnipeg, Manitoba, Canada R3T 2N2 (e-mail: john_bullied@umanitoba.ca); and* [2]*Department of Botany, University of Manitoba, Winnipeg, Manitoba, Canada R3T 2N2.* *Received 25 February 2005, accepted 21 November 2005.*

Bullied, W. J., Van Acker, R. C., Marginet, A. M. and Kenkel, N. C. 2006. **Agronomic and environmental factors influence weed composition and canola competitiveness in southern Manitoba.** Can. J. Plant Sci. **86**: 591–599. Canola yield in Manitoba has reached a plateau in recent years. The causes for this, as related to agronomic, environmental, weed interference and canola competitiveness factors, were identified using observational data from 31 canola fields in southern Manitoba in a 2-yr on-farm research study. Agronomic and environmental factors contributing to weed density and composition were determined with multivariate canonical correspondence analysis. Agronomic and environmental factors most influential on absolute and relative canola biomass were determined with multiple regression analysis. Most weeds were adaptable across a broad range of crop environments; however, some functional groups of weeds were either positively or negatively favored by specific environmental or agronomic conditions. Absolute canola biomass prior to bolting was greater as soil growing degree days (GDD) increased and canola was dense and seeded early. Lower weed density, increased soil GDD, and reduced surface soil moisture were significant factors contributing to higher relative canola biomass. Results from this study indicate that seeding canola early and at a rate sufficient to achieve a dense crop stand can increase canola competitiveness and reduce weed interference.

Key words: Agronomy, canola, competitiveness, environment, weeds

Bullied, W. J., Van Acker, R. C., Marginet, A. M. et Kenkel, N. C. 2006. **Les paramètres agronomiques et environnementaux influent sur la composition des adventices et sur la compétitivité du canola dans le sud du Manitoba**. Can. J. Plant Sci. **86**: 591–599. Depuis quelques années, le rendement du canola a atteint un plateau au Manitoba. Les auteurs ont cherché les raisons de ce problème au niveau de l'agronomie, de l'environnement, de la concurrence des adventices et de la compétitivité du canola en analysant les observations effectuées dans 31 champs de canola du sud du Manitoba lors d'un projet de deux ans poursuivi sur le terrain. Ils ont ainsi déterminé les facteurs agronomiques et environnementaux qui affectent la densité et la composition des peuplements d'adventices par une analyse factorielle de correspondance canonique à variables multiples. Les paramètres agronomiques et environnementaux qui exercent la plus grande influence sur la biomasse absolue et relative du canola ont été établis par analyse de régression multiple. La plupart des adventices s'adaptent à une vaste gamme de milieux, dans les cultures, mais certaines conditions agricoles ou environnementales ont une incidence positive ou négative sur quelques groupes fonctionnels de mauvaises herbes. La biomasse absolue du canola avant la montaison augmente avec la hausse du nombre de degrés-jours de croissance et lorsqu'on sème la culture hâtivement à une grande densité. Une faible densité de peuplement des adventice, un nombre accru de degrés-jours de croissance et une teneur en eau plus faible dans le sol de surface sont des facteurs qui favorisent sensiblement une biomasse relative plus élevée du canola. Les résultats de l'étude laissent croire qu'on peut atténuer la concurrence des adventices et accroître la compétitivité du canola en le semant tôt à un taux adéquat pour parvenir à une forte densité de peuplement.

Mots clés: Agronomie, canola, compétitivité, environnement, adventices

Canola has recently rivaled wheat as the most important crop in Manitoba in terms of gross income (Statistics Canada 2004). Yield trends for canola, however, have shown that since the mid 1990s, yields have remained relatively flat, and indications are that canola may have reached a yield plateau (Statistics Canada 2004). Causes contributing to the leveling of canola yield trends may be agronomic (Johnson et al. 1995; Angadi et al. 2003; Harker et al. 2003; Clayton et al. 2004), environmental (Nuttall et al. 1992; Brandt and McGregor 1997) or genetic (Harker et al. 2000, 2003; Clayton et al. 2004) in nature. Because weed growth is perceived by producers as being the greatest cause of yield loss in agricultural crops (Owen 1998), one of the most important weed management strategies is to grow a competitive crop. Therefore, determining agronomic and environmental factors most conducive to crop emergence and growth can be a useful management strategy to enhance crop competitiveness and reduce interference by weeds. Crop competitiveness indicates dense, rapid crop seedling emergence and vigorous canopy development relative to that of weeds (Zimdahl 2004). Shading by the crop canopy is an important component of plant competition to inhibit weed seedling germination (Anderson and Nielson 1996), because weed emergence often occurs over an extended period of time (Zimdahl 2004; Spandl et al. 1998). The rel-

Abbreviations: **CA**, correspondence analysis, **CCA,** canonical correspondence analysis; **GDD,** growing degree days ative timing of crop and weed emergence is an important determinant of competition (Radosevich and Roush 1990; O'Donovan 1992). A number of environmental factors contribute to the germination and emergence of weeds in canola, including soil thermal accumulation and soil water potential (Egley 1986; Forcella et al. 2000). Initial weed seedling germination is governed by a temperature or water threshold (Bradford 2002), whereas weed seedling emergence timing is dependent on recruitment depth (du Croix Sissons et al. 2000), and thermal accumulation (Forcella et al. 2000; Bullied et al. 2003).

Weeds can be highly adaptive to a wide range of environments (Mohler 2001b), and the extent of weed interference in a crop and competition for resources depends on a weed's adaptation to environmental conditions, as well as agronomic practices associated with crop production (Aldrich and Kremer 1997; Leeson et al. 2000). Weed interference can be reduced by altering the environment that a weed is adapted to; however, this can result in shifts in weed composition (Aldrich and Kremer 1997). Reducing weed competitiveness and growth in the current crop also has important implications for the weed seedbank and future weed populations.

The combined effects of particular weed communities, farming systems and environmental conditions will influence canola competitiveness. A number of agronomic factors including tillage intensity (Derksen et al. 1993; McGiffen et al. 1997; Blackshaw et al. 2001), fertility management (DiTomaso 1995), cultivar type (Harker et al. 2003), time of seeding (Mohler 2001a; Bullied et al. 2003), and seeding rate (O'Donovan 1994) can be used to enhance crop competitiveness with weeds. Optimal time of seeding with quality seed will favor crop growth and competitiveness. Tillage systems that decrease soil disturbance due to soil conservation management have generally retained greater amounts of surface residue cover, with resultant modifications to the soil environment and weed community (Mohler and Calloway 1992; Derksen et al. 1993; Blackshaw et al. 2001).

Multiple benefits are associated with increased canola competitiveness. A lower requirement for in-crop herbicides results from reduced weed interference and fewer smaller weeds, which are easier to kill with herbicides (Andres and Clement 1984). The resulting lower herbicide dependence reduces herbicide resistance in weeds and residue in the environment. Environmental and herbicide resistance issues have increased in recent years, prompting the interest in using crop competitiveness in integrated weed management programs (DiTomaso 1995; Zand and Beckie 2002; Harker et al. 2003).

Crop competitiveness is often determined by absolute grain yield under weed-free conditions, indicating the yielding ability of the crop, relative grain yield in the presence of weeds indicating crop competitive ability, and weed biomass indicating weed suppression ability (Mortensen et al. 2000). In canola, weed competition occurs primarily before bolting (Martin et al. 2001). Weeds that initially reduce canola density can be killed or severely stunted by canopy closure after bolting (Martin et al. 2001).

Since it can be concluded that canola competitiveness could be assessed by measuring canola and weed biomass at the canola bolting stage, this investigation models agronomic and environmental factors associated with canola production at the canola bolting stage. The purpose was to determine field conditions that have the greatest predictive ability for canola competitiveness and weed interference. This study investigates agronomic and environmental factors influencing (1) weed density and composition in canola, and (2) canola biomass at bolting stage and competitive ability of canola in Manitoba.

MATERIALS AND METHODS

Study Area

A study was conducted across southern Manitoba in 31 spring-seeded canola fields during the spring of 1999 and 2000 to determine the competitive ability of canola over a broad range of field conditions. Fields were located across seven ecodistricts located within three ecoregions encompassing a wide array of agronomic and environmental factors associated with canola production (Fig. 1, Table 1). The previous crop grown was spring wheat, barley or oats in all fields, except one, which was previously summerfallow. All fields were free of soil residual herbicides for at least 1 yr prior to the study. No treatment conditions in addition to normal farming practices were imposed on the experimental units.

Agronomic Methods

Canola and weed emergence data were collected every 2 to 4 d from the time of seeding until the canola bolting stage (midseason vegetative stage). All observed weed species were recorded bi-weekly by marking each emerging weed with colored rings and summing cumulative emergence until the canola bolting stage (Table 2). Monitoring of fields ended at the canola bolting stage. Four permanent 0.25-m^2 quadrats were placed in each field at least 50 m away from field edges in areas considered generally representative of the field. Newly emerged canola and weed seedlings were identified at each field visit, and total density of each species was recorded. To protect weed seedlings from in-crop herbicide damage, all quadrats were covered with a white, non-permeable plastic sheet during in-crop herbicide applications. Canola and weed aerial biomass was harvested at ground level from each of the four quadrats at the canola bolting stage, and separated by species. Samples were dried at 80°C for 48 h and the weight was recorded on a dry basis.

Agronomic Factors

In this study, tillage intensity was categorized into one of two broad-based tillage system classifications, based on the amount of tillage in a particular field. To facilitate analysis, relative rankings were given to tillage based on tillage intensity: low disturbance = 1; high disturbance = 2. High disturbance fields were tilled at least twice prior to seeding, either in the fall or spring. Applications of fertilizer, which were incorporated into the soil, were considered to be one tillage pass. Low disturbance fields had no tillage other than seeding and fertilizer application at least 3 yr prior to this study. Low dis-

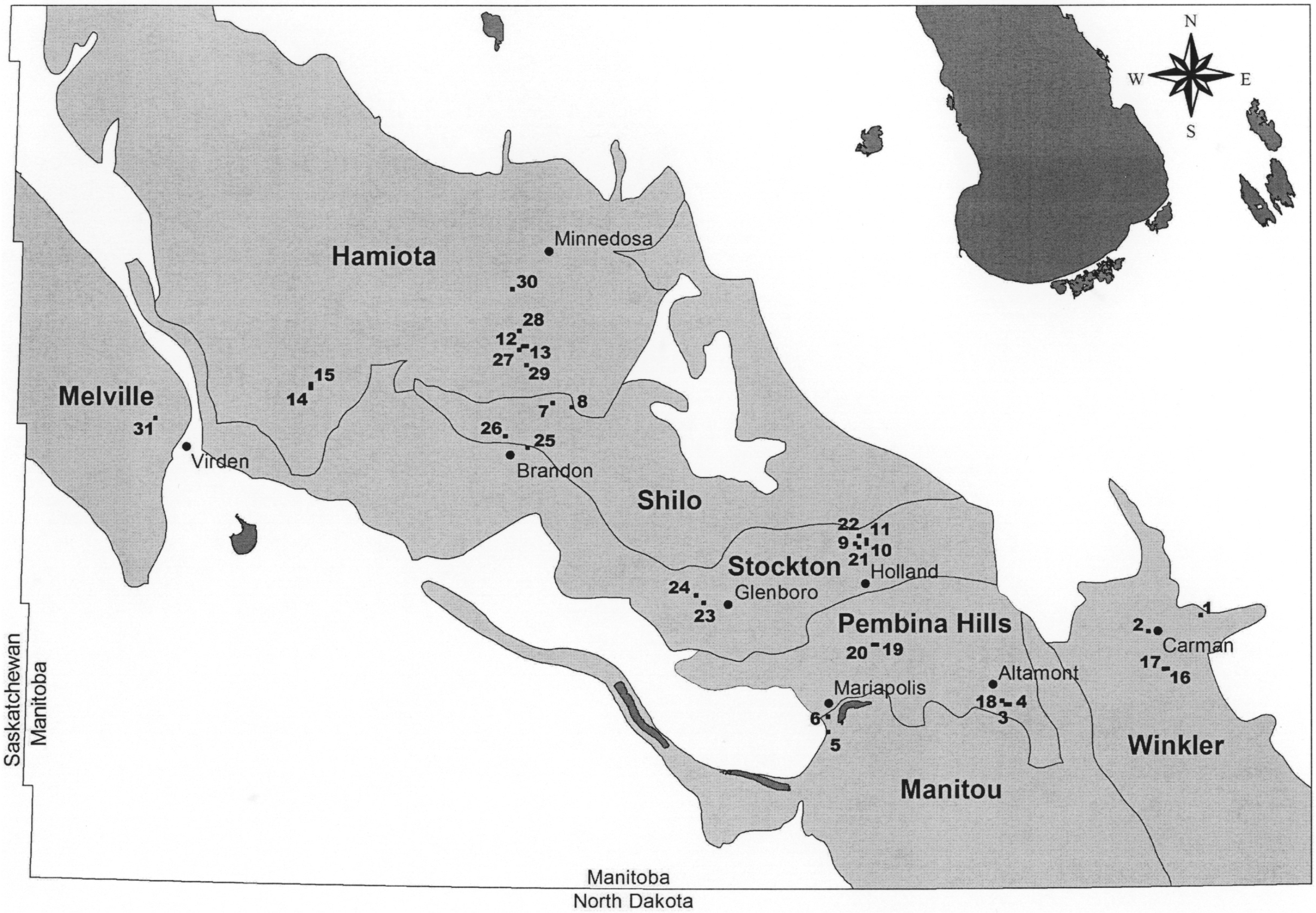

Fig. 1. Location of quarter sections in southern Manitoba containing 31 fields in the study georeferenced within ecodistricts where fields = ■, and ecodistricts are pale shaded areas labeled in bold font. Local towns = ●, with labels in normal font.

Table 1. Environmental characteristics of ecoregions and ecodistricts containing fields sampled in the study[z]

Ecoregion Ecodistrict	Soil textural class[y]	Soil moisture deficit (mm)	Growing degree-days[x] (°C)	Annual precipitation (mm)
Aspen Parkland				
Melville (1)[w]	Loam	254	1546	441
Hamiota (8)	Clay loam	183	1480	463
Shilo (3)	Sandy loam	209	1650	482
Stockton (8)	Sandy loam	250	1674	493
Manitou (2)	Clay loam	162	1689	381
Lake Manitoba Plain				
Winkler (4)	Clay loam	207	1796	514
Southwest Manitoba Uplands				
Pembina Hills (5)	Clay loam	154	1671	541

[z] Agriculture and Agri-Food Canada (1999).
[y] Agriculture and Agri-Food Canada (1989).
[x] Annual growing degree-days (GDD) above base temperature of 5°C.
[w] Number of fields represented in each ecodistrict.

turbance tillage required the use of only one or two passes with the use of narrow soil openers (width ≤ 2.5 cm), to minimize the amount of soil disturbance. Fields that had a separate application of fertilizer with the use of narrow soil openers were still categorized as low disturbance tillage fields. Residue cover for each of four quadrats in each field was determined immediately after seeding by digital analysis of photographs taken at an angle perpendicular to the ground surface. Photographs were digitized with a flatbed scanner. Assess™ image analysis software (American Phytopathological

Table 2. Bayer weed code, scientific name, common name, growth habit, rank order of species abundance, mean plant density and density range for canola and weed species

Code	Scientific name	Common name	Growth habit	Rank	Mean density (no. m^{-2})	Density range (no. m^{-2})
ACENE	*Acer negundo* L.	Manitoba maple	Perennial dicot	20	<1	3
AGRRE	*Elytrigia repens* (L.) Nevski	Quackgrass	Perennial graminoid	26	<1	2
AMARE	*Amaranthus retroflexus* L.	Redroot pigweed	Annual dicot	7	8	106
ARBTH	*Arabidopsis thaliana* (L.) Heynh.	Mouse-ear cress	Annual dicot	11	4	130
AVEFA	*Avena fatua* L.	Wild oat	Annual graminoid	2	81	1114
BRSNS[z]	*Brassica napus* L.	Canola (Argentine)	Annual dicot	1	105	170
CAPBP	*Capsella bursa-pastoris* (L.) Medikus	Shepherd's-purse	Annual dicot	18	1	18
CHEAL	*Chenopodium album* L.	Common lambsquarters	Annual dicot	9	5	51
CIRAR	*Cirsium arvense* (L.) Scop.	Canada thistle	Perennial dicot	23	<1	2
DESSO	*Descurainia sophia* (L.) Webb. ex Prantl	Flixweed	Annual dicot	26	<1	1
EPHSE	*Euphorbia serpyllifolia* Pers.	Thyme-leaved spurge	Annual dicot	17	1	23
GAETE	*Galeopsis tetrahit* L.	Common hempnettle	Annual dicot	12	3	80
GALAP	*Galium aparine* L.	Catchweed bedstraw (cleavers)	Annual dicot	16	1	35
HORVU[y]	*Hordeum vulgare* L.	Barley	Annual graminoid	10	5	74
KCHSC	*Kochia scoparia* (L.) Schrad.	Kochia	Annual dicot	26	<1	2
MALPU	*Malva pusilla* Sm.	Round-leaved mallow	Annual dicot	22	<1	4
MELAL	*Silene alba* (Mill.) E.H.L. Krause	White campion (cockle)	Annual dicot	19	<1	6
POLCO	*Polygonum convolvulus* L.	Wild buckwheat	Annual dicot	4	27	353
POLPE	*Polygonum persicaria*	Annual smartweed (ladysthumb)	Annual dicot	14	2	29
SASKR	*Salsola iberica* Sennen & Pau	Russian thistle	Annual dicot	15	2	49
SETVI	*Setaria viridis* (L.) Beauv.	Green foxtail	Annual graminoid	3	78	297
SINAR	*Brassica kaber* (DC.) L. C. Wheeler	Wild mustard	Annual dicot	5	16	188
SONAR	*Sonchus arvensis* L.	Perennial sowthistle	Perennial dicot	29	<1	1
SONOL	*Sonchus oleraceus* L.	Annual sowthistle	Annual dicot	25	<1	1
STEME	*Stellaria media* (L.) Vill.	Common chickweed	Annual dicot	6	11	207
TAROF	*Taraxacum officinale* Weber in Wiggers	Dandelion	Perennial dicot	21	<1	4
THLAR	*Thlaspi arvense* L.	Field pennycress (stinkweed)	Annual dicot	8	6	53
TRZAS[y]	*Triticum aestivum* L.	Wheat	Annual graminoid	13	2	31
VICVI	*Vicia villosa* ROTH	Hairy vetch	Annual dicot	23	<1	4

[z] Seeded crop.

[y] Volunteer crop.

Society, St. Paul, MN) was used to determine the percentage of residue cover by contrasting plant residue against the soil background in the digital images. Residue cover for each field was expressed as a percentage of total ground cover and was determined by averaging the results of the four quadrats within each field. Seeding dates for canola were expressed as air growing degree-days for analysis, and ranged in calendar date from May 01 to Jun. 16 in 1999, and from Apr. 26 to May 19 in 2000. Seeding dates and tillage practices for canola were representative for southern Manitoba (Thomas et al. 1999). Canola type was represented by 21 open-pollinated fields and 10 hybrid fields, and was expressed as ordinal data with open pollinated = 1 and hybrid = 2.

Environmental Factors

Soil textures of the fields, which ranged from sandy loam to clay loam, were determined by their legal description on the Canada Land Inventory maps (scale 1:1 000 000) (Agriculture and Agri-Food Canada 1989). Fields were ranked into one of three soil texture classes based on clay content and reduced internal drainage: sandy loam = 1; loam = 2; clay loam = 3. Daily air temperature was recorded for each field from the nearest Environment Canada weather station in order to determine air thermal accumulation at seeding time. In each field, soil temperatures were recorded continuously from the time of seeding and throughout the sampling period at a depth of 2.5 cm below the soil surface using StowAway TidbiT® temperature loggers (Onset Computer Corporation, Bourne, MA). Cumulative GDD were calculated from summed daily mean soil temperature recordings from the time of seeding in each field until the canola bolting stage using the equations,

$$GDD_{\text{daily}} = \left(\left[T_{\max} + T_{\min}\right]/2\right)T_{\text{base}}$$

$$\text{and } GDD = \sum_{i=1}^{n} GDD_{\text{daily}} \tag{1}$$

where $T_{\max}$ is the maximum daily soil temperature, $T_{\min}$ is the minimum daily soil temperature, T_{base} is the base temperature (5°C), and n is the elapsed number of days from the time of seeding. A base temperature of 5°C was used as a biologically justifiable base to reflect the germination and emergence of canola, below which no biological activity for canola was deemed to occur. Where daily mean soil temperature was 5°C or less, $\text{GDD}_{\text{daily}}$ equaled 0. Cumulative GDD was derived for each day by summing $\text{GDD}_{\text{daily}}$ beginning at seeding until canola bolting. Seed zone gravimetric soil moisture was measured to a depth of 2.5 cm in each quadrat at each site at intervals of 3 to 4 d post-seeding until the time of canola bolting. Gravimetric soil moisture was averaged over all sampling dates from seeding until canola bolting for each field.

Data Analyses

Weed species density was standardized by logarithmic transformation prior to multivariate analysis to normalize the data distribution and reduce the influence of data outliers. Canonical correspondence analysis (CCA) in Canoco™ (ter Braak and Smilauer 1998) was used to model the canonical relationship between weed species density and environmental factors by constraining the weed species to the agronomic and environmental factors (ter Braak and Prentice 1988; Kenkel et al. 2002). CCA selects linear combinations of factor variables (environment) to best explain variation in ordination scores obtained from response variables (weed density) (ter Braak 1995). The option to down weight the influence of rare species in the analysis was used in Canoco™ (ter Braak 1998). A two-dimensional ordination was graphed from the CCA scores for the first two axes with symmetric scaling of samples and species to better display relationships. Vectors from the origin of the ordination represent field environmental variables. The direction of vectors indicates the maximum association of weeds with environmental variables. The length of vectors indicates the strength of the association between weeds and environmental variables.

Multiple regression with forward selection was used to model canola biomass as a function of agronomic and environmental factors previously described (SAS Institute, Inc. 1999). Autocorrelated factors were eliminated from the model, and both linear and quadratic terms were investigated. Rankings for soil texture and tillage as described earlier were used in the multiple regression model. Weed composition was derived from a correspondence analysis (CA) ordination of the relationship between logarithmic transformed weed species density and fields by obtaining species scores from the second axis of the biplot. The second axis in the ordination biplot represents compositional differences among the majority of weed species (Table 3). The coefficient of multiple determination (R^2) explains the percent of variance in canola biomass by the environmental and agronomic factors. Selection of relevant explanatory variables in the appropriate reduced multiple regression model is based on contribution to model R^2, as well as minimizing the Mallow's (C)p statistic in the full regression model of factors meeting the 0.50 significance level (Tables 4 and 5). Factors not meeting the 0.50 significance level were not included in the full regression model.

RESULTS AND DISCUSSION

Weed Community

The weed community was characterized by a CCA ordination, which constrained weed species density to environmental and agronomic factors (Fig. 2). The majority of weeds were shown to occur across a broad range of crop environments. Because substantial spatial variation in ecologically significant characteristics occur in many weed species (Mohler 2001b), it is reasonable to suggest that many weeds can be highly adaptable to a wide range of field conditions. Some functional groups of weeds, however, were either positively or negatively favored by specific environmental or agronomic conditions. Limitations exist when relating weed species based on common functional traits to tillage system response, due the absence of species biology and ecology for local conditions (Thomas et al. 2004). Annual grasses, including volunteer wheat, volunteer barley, green foxtail, and wild oats, which are located centrally in the ordination, are characterized as being abundant across the majority of fields (Fig 2). The presence of volunteer crops is dependent on the previous rotation. Wild oats and green foxtail are the two most abundant weeds in annual cropping systems in Manitoba (Thomas et al. 1999; Van Acker et al. 2000; Leeson et al. 2002).

The first axis displayed a disturbance gradient in which low disturbance tillage perpetuated perennial broadleaf weed species such as perennial sowthistle, dandelion, Manitoba maple and Canada thistle, possibly due to less disruption to the established perennial root system. A shift in weed composition toward perennial species under conservation tillage was previously observed (Derksen et al. 1993; Swanton et al. 1993; Buhler et al. 1994). Quackgrass was associated with high disturbance tillage (Fig. 2), possibly because its rhizomatous root system is relocated by tillage (Lemieux et al. 1993). The continued use of systemic herbicides during no-till burn-off in conservation tillage systems (Merivani 1985; Chandler et al. 1994; Harker and Vanden Born 1997) where quackgrass is growing at a time that control is influenced reduces the incidence of quackgrass in conservation tillage systems.

The second axis in the CCA ordination displayed a moisture gradient (Fig. 2). Drought-tolerant weeds including kochia, Russian thistle, and green foxtail were associated with greater thermal accumulation and lower soil moisture on the second axis. Previous studies determined that these species, which have C_4 metabolism, flourish in warm, dry soils (Wiese and Vandiver 1970; Dwyer and Wolde-Yohannis 1972; Wall and Friesen 1990; Nord 1999). In the present study, as in others, flixweed (Mitich 1996), perennial sowthistle (Zollinger and Kells 1991), and quackgrass (Young et al. 1983) are associated with wetter field conditions. In a study of contributing factors of weed community composition in spring-seeded crops in Manitoba, soil type was determined to be a more important correlate of weed composition compared with cultural practices (Dale et al. 1992).

Redroot pigweed, lambsquarters and green foxtail were inhibited by greater amounts of field residue and canola biomass (Fig. 2). This may be due to increased shading of the soil surface because these weed species require light for germination (Gallagher and Cardina 1998; Mohler and Calloway 1992). Rare weed species including mouse-ear cress and catchweed bedstraw, occurring in 10% or less of fields, were primarily associated with decreased soil disturbance and earlier seeding dates. The emergence of rare species may be attributed to a greater number of available niches in a less-disturbed soil environment, earlier in the season, or later in the season after the application of in-crop herbicides or no herbicide (covered quadrats).

Canola Competitiveness

The full regression model of environmental and agronomic predictors of absolute canola biomass yield is shown in Table 4. The appropriate reduced model included three factors as determined by factor contribution to model R^2 and

Table 3. Correspondence ordination biplot composite scores representative of compositional differences among weed species

	Composite scores	
Weed species	Axis 1	Axis 2
ACENE	–0.075	–0.165
AGRRE	–1.004	–1.639
AMARE	–0.466	–0.044
ARBTH	5.363	–1.031
AVEFA	–0.273	–0.258
CAPBP	–0.354	–0.580
CHEAL	–0.611	–0.939
CIRAR	–0.683	–0.205
DESSO	–0.669	–1.872
EPHSE	–0.770	2.364
GAETE	3.216	0.378
GALAP	5.363	–1.031
HORVU	–0.245	2.871
KCHSC	–0.860	1.105
MALPU	–0.531	–1.422
MELAL	0.398	–1.555
POLCO	–0.378	–0.075
POLPE	0.141	1.969
SASKR	–0.837	–4.217
SETVI	–0.093	–0.363
SINAR	–0.467	1.322
SONAR	–0.739	4.537
SONOL	–0.769	2.940
STEME	2.360	0.697
TAROF	–0.359	2.317
THLAR	0.520	–0.038
TRZAS	–0.203	–0.889
VICVI	0.072	1.669

Table 4. Summary of factors meeting the 0.50 significance level for entry into the model predicting absolute canola biomass yield

Factor	Partial R^2	Model R^2	Mallow's C(p)	$P > F$
Soil GDD^2	0.448	0.448	3.63	<0.001
Canola density	0.075	0.523	1.49	0.045
Seeding date (air GDD)	0.067	0.590	–0.23	0.045
Soil moisture	0.018	0.607	0.79	0.288
Tillage	0.011	0.618	2.20	0.414

Table 5. Summary of factors meeting the 0.50 significance level for entry into the model predicting relative canola biomass yield

Factor	Partial R^2	Model R^2	Mallow's C(p)	$P > F$
Weed density	0.382	0.382	45.19	<0.001
Soil moisture	0.160	0.542	28.46	0.004
Soil GDD	0.124	0.667	15.93	0.004
Tillage	0.018	0.684	15.88	0.240
Residue	0.032	0.716	14.19	0.108
Seeding date (air GDD)	0.019	0.735	13.96	0.201
Canola type	0.028	0.763	12.70	0.114
Canola density	0.010	0.773	13.57	0.344
Weed composition	0.029	0.801	12.23	0.097
Soil texture	0.028	0.829	11.00	0.087

Mallow's (C)p statistic (Table 4). The model best predicting canola biomass yield was $Y = -12.54751 + 0.00053(\text{soil GDD})^2 - 0.12984(\text{seeding date}) + 0.45358(\text{canola density})$. Soil thermal accumulation, which has considerable biological rational, was the factor that most influenced canola biomass yield (as measured by R^2) compared with other environmental and agronomic factors monitored in this study. The coefficient of determination (R^2) from a regression equation relating plant response to competition is used as a measure of competition (Welden and Slauson 1986).

The next most influential factor contributing to biomass yield of canola was seeding date. Later seeding dates contributed negatively to canola biomass yield, probably as a result of lower accumulated GDD and reduced availability of resources later in the season. Earlier spring seeding dates for canola have been shown to provide greater yield potential for canola compared with late spring (Angadi et al. 2003; Clayton et al. 2004) or fall seeding (Kirkland and Johnson 2000; Karamanos et al. 2002; Clayton et al. 2004).

The third factor in the model, canola density, contributed positively to an increase in biomass production. Biomass normally increases as plant population increases despite plastic response of canola (Angadi et al. 2003); however, increasing canola density beyond a minimum value will not necessarily increase crop yields (Potter et al. 1999).

Increased biomass production in canola can generally be achieved by altering agronomic practices that can result in greater plant population by use of hybrid seed (Harker et al. 2003), increased seeding rate (Harker et al. 2003; O'Donovan et al. 2004), and improved seeding methods to obtain seedling uniformity (Angadi et al. 2003). Weed density did not enter the regression model as a significant predictor of absolute canola biomass yield. This may be due to the lack of resource limitations in some fields where canola was able to coexist with high weed densities, or it could mean that the number of small weeds has little influence on canola biomass compared with other predictors.

Relative canola biomass was best predicted by three environmental and agronomic factors from the full model (Table 5). The fitted reduced model was $Y = 0.85697 - 0.00086(\text{weed density}) + 0.00115(\text{soil GDD}) - 0.01589(\text{soil moisture})$. Relative canola biomass yield was most affected by weed density, which indicates that a greater weed density contributed to a decrease in relative canola biomass. Canola is generally limited by weed interference at an early stage of canola development (Chow and Dorrell 1979; Martin et al. 2001; Clayton et al. 2002), or by late emerging weeds after the time of in-crop herbicide control (Clayton et al. 2002). As well, Daugovish et al (2002) determined that canola biomass yield per plant was affected more by interspecific competition with wild oat than by intraspecific competition with canola, indicating the importance of maintaining adequate canola density.

The second factor, soil GDD, increased the canola biomass relative to that of weeds. This probably occurred because, on average, seeded canola emerges earlier than most weeds (Bullied et al. 2003). Since canola has more advanced development than weeds, it can take greater advantage of thermal accumulation.

The final factor in the reduced model, surface soil moisture, caused reduced relative canola biomass. This may be the result of late spring recruitment of weeds during environmental conditions favorable for germination prior to closure of the crop canopy. Surface soil moisture is more

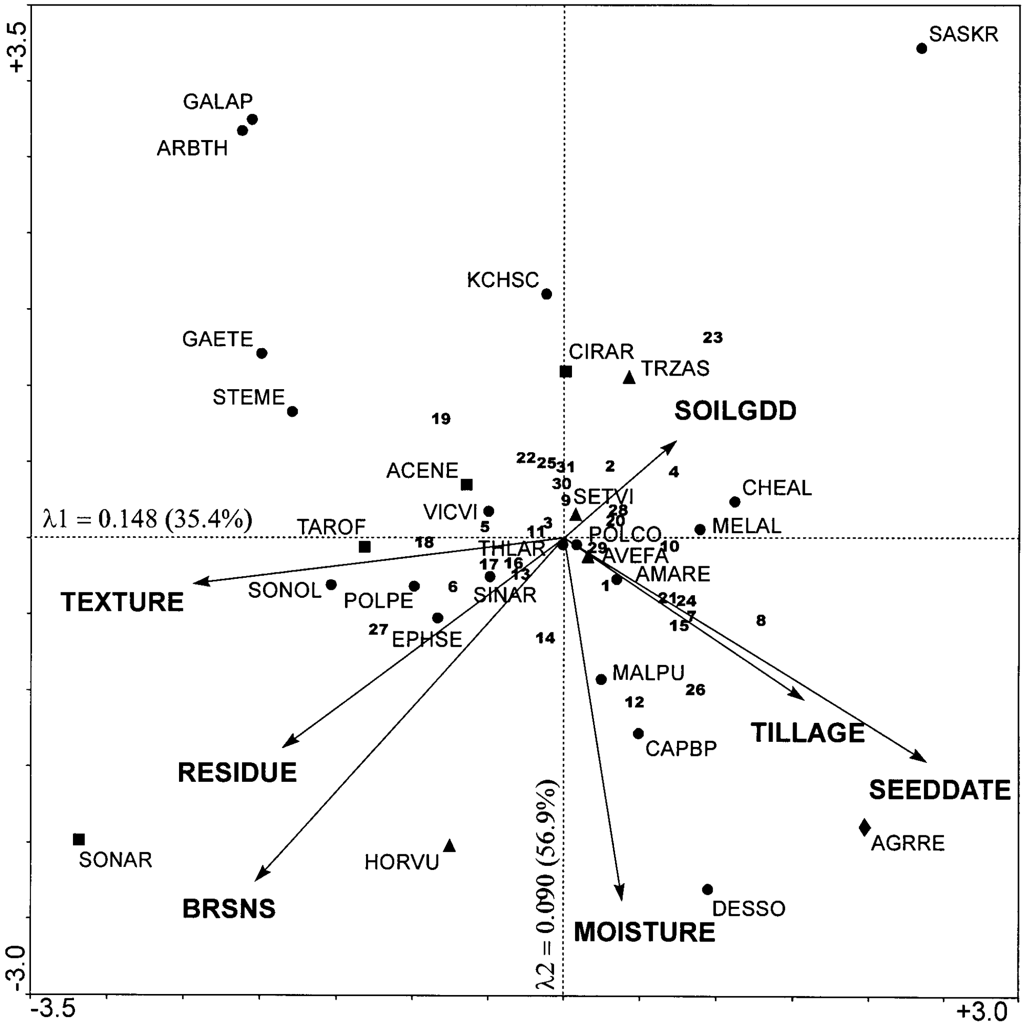

Fig. 2. Canonical correspondence analysis ordination triplot of weed species density indicated by functional group where annual dicots = ●, perennial dicots = ■, annual graminoids = ▲, and perennial graminoids = ◆, constrained by environmental and agronomic factors (shown as vectors). Species are specified by WSSA codes (see Table 2 for common names). Fields are specified by number. Eigenvalues for each axis are specified by (λ) with cumulative percentage variance of species–environment relation. Species–environment canonical correlations are 0.775 and 0.761 for axis 1 and axis 2, respectively. Redundancy is 26.8%.

readily available to weeds recruiting from a shallow depth than the canola. Since canola was generally seeded at an average depth of 2 to 2.5 cm, its root development is deeper than many weed seeds in the seedbank (du Croix Sissons et al. 2000).

Canola type was a non-significant determinant of canola yield in this study. This may have been a result of relatively low weed interference in some fields in which canola expressed little difference in competitiveness among cultivar types (Zand and Beckie 2002). Other agronomic and environmental factors were shown to be more important biomass determinants. The importance of hybrid canola varieties cannot be minimized, however, because in cases of high weed interference, such cultivars have been shown to be more competitive than open pollinated ones (Zand and Beckie 2002; Harker et al. 2003).

SUMMARY

Although weed composition did not influence canola biomass yield in this study, high weed density was shown to have a detrimental effect on relative canola biomass yield. Since most weeds were shown to be highly adaptive across a wide range of environmental conditions, it can be inferred that weed density is more important than composition in predicting relative canola biomass yield. However, weed density proved not to be a significant predictor of absolute canola biomass yield. Early seeding was shown to increase yield and competitiveness of canola, possibly as a result of improved resource capture and earlier canopy closure. Depending on the relative time of weed emergence and density, herbicides may not be necessary for weed control (Andres and Clement 1984). Management practices that can reduce weed density below threshold levels would therefore reduce herbicide use, resulting in reduced control costs for producers, reduced selection pressure on weeds to develop herbicide resistance, and less pesticide in the environment. The results from this study confirm that early seeding of canola and high stand density can contribute significantly to higher biomass yield and competitiveness of canola. The results also show that canola biomass yield and competitiveness are enhanced by warm soil temperatures (high soil GDD). The results for soil GDD and seeding date effect on canola biomass yield and competitiveness suggest that in order to optimize canola productivity, farmers should seed early as long as soil temperatures are sufficiently warm to allow for canola germination and emergence.

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